(54) Title: MULTIPLEXING METHOD IN A MULTI CARRIER TRANSMIT DIVERSITY SYSTEM
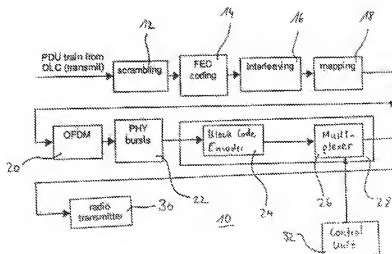
(57) Abstract: Multiplexing Method in a Multi Carrier Transmit Diversity SystemThe invention relates to a method of multiplexing data words in a multicarrier transmit diversity system. The method comprises the step of generating a plurality of data blocks, each data block comprising data words and each data word containing data symbols derived from a data signal, the step of determining a data transmission constraint if the data words of said one or more data blocks are to be multiplexed in the time domain or in the frequency domain and the step of multiplexing the data words of the data blocks in accordance with the determination result.

Multiplexing Method in a
Multi Carrier Transmit Diversity System

BACKGROUND OF THE INVENTION

Technical Field

The present invention relates to the field of transmit an-
tenna diversity and in particular to a method of multiplexing
data words in a multi carrier transmit diversity system. The
invention also relates to a multiplexer for multiplexing a
sequence of data symbols and a demultiplexer for demultiplex-
ing a multiplexed sequence of data symbols.

Discussion of the Prior Art

Peak transmission rates in wireless communication systems
have steadily increased during the last years. However, peak
transmission rates are still limited for example due to path
loss, limited spectrum availability and fading.

Transmitter diversity is a highly effective technique for
combating fading in wireless communications systems. Several
different transmit diversity schemes have been proposed. In
Li, Y.; Chuang, J.C.; Sollenberger, N.R.: Transmitter diver-
sity for OFDM systems and its impact on high-rate data wire-
less networks, IEEE Journal on Selec. Areas, Vol. 17, No. 7,
July 1999 the transmit diversity schemes of delay, permuta-
tion and space-time coding are examplarily described. Accord-
ing to the delay approach, a signal is transmitted from a
first transmitter antenna and signals transmitted from fur-
ther transmitter antennas are delayed versions of the signal
from the first transmitter antenna. In the permutation
scheme, the modulated signal is transmitted from a first
transmitter antenna and permutations of the modulated signal

are transmitted from further transmitter antennas. By means
of space-time coding a signal is encoded into several data
words and each data word is transmitted from a different
transmitter antenna. During transmission the data words are
spread (or multiplexed) in the time domain by successively
transmitting the data symbols of a data word over a single
carrier frequency.

A further transmit diversity scheme for a multicarrier system
is space-frequency coding. By means of space-frequency coding
a signal is encoded into several data words and each data
word is spread (or multiplexed) in the frequency domain by
transmitting the data symbols of each data word on orthogonal
frequencies, i.e. orthogonal subcarriers. An exemplary scheme
for space-frequency coding is described in Mudulodu, S.;
Paulraj, A.: A transmit diversity scheme for frequency selec-
tive fading channels, Proc. Globecom, San Francisco, pp.
1089-1093, Nov. 2000. According to the multicarrier system
described in this paper, the data words relating to an en-
coded signal are preferably multiplexed in the time domain
although orthogonal frequencies are available and the data
words could thus also be multiplexed in the frequency domain.
This is due to the fact that if multiplexing in the frequency
domain is utilized the employed frequencies, i.e. subcarri-
ers, must see the same channel, which may not always be pos-
sible in a frequency selective fading channel. However, in
case the subcarriers experience the same channel, it is
stated that either multiplexing in the time domain or multi-
plexing in the frequency domain or a combination of the two
may be used. By combining multiplexing in the time domain and
in the frequency domain the data symbols of a data word are
simultaneously multiplexed in the time domain and in the fre-
quency domain. This means that the data word is spread both
across time and across frequencies.

Departing from the various transmit diversity schemes hith-
erto known there is a need for a method of multiplexing data

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words in a multicarrier transmit diversity system which can
easily be adapted to the specifications of different wireless
communications systems. There is also a need for a corre-
sponding multiplexer and a demultiplexer.

BRIEF DESCRIPTION OF THE INVENTION

The existing need is satisfied by a method of multiplexing
data words in a multicarrier transmit diversity system which
comprises the step of generating a plurality of data blocks,
each data block comprising data words and each data word con-
taining data symbols derived from a data signal, the step of
determining for one or more of the data blocks in dependence
on at least one transmission constraint if the data words of
said one of more data blocks are to be multiplexed in a time
domain or in a frequency domain and the step of multiplexing
the data words of the data blocks in accordance with the re-
sult of the determination.

The multiplexing method of the invention is not restricted to
a specific transmit diversity scheme as long as the utilized
transit diversity scheme enables to generate from a data sig-
nal a plurality of data blocks having the above structure.
For example, the transmit diversity schemes of block coding
and of permutation allow to generate such data blocks. Pref-
erably, the generated data blocks have the structure of a ma-
trix similar to a space-time block code (STBC) matrix. Also,
it is not required that the transmit diversity scheme guaran-
tees full transmit diversity. In other words: the invention
does not necessitate that each information symbol comprised
within the data signal is transmitted from each transmitter
antenna. Nonetheless, a preferred embodiment of the invention
comprises the feature of full transmit diversity.

Moreover, the invention is not restricted to any number of
transmit and receive antennas. Preferably, the number of data
words per data block equals the number of transmit antennas

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such that each data word of a data block may be transmitted
from an individual transmitter antenna. If more than one re-
ceive antenna is provided, the receive diversity scheme of
maximum-ratio combining can be applied. However, other re-
5   ceive diversity schemes may be used as well.

According to the invention, it is decided on a data block
level how the data words are to be multiplexed. The decision
on the data block level allows to change the multiplexing do-
10   main from one data block to a subsequent data block which is
advantageous if one has to cope with specific predefined or
varying transmission constraints. Also, the multiplexing
method according to the invention can be applied in various
wireless communication systems without major changes due to
15   the specific multiplexing flexibility gained by selecting the
multiplexing domain on the data block level. The multiplexing
domain can be determined for each data block individually or
simultaneously for a plurality of data blocks. For example,
it can be decided for a sequence of data blocks that all data
20   words comprised within the sequence of data blocks are to be
multiplexed in either the time domain or in the frequency do-
main.

The multiplexing domain is determined by taking into account
25   one or more transmission constraints. For example, the trans-
mission constraints may comprise one or more physical trans-
mission constraints or one or more data-related transmission
constraints. It can also comprise both one or more physical
transmission constraints and one or more data-related trans-
30   mission constraints. The physical transmission constraints
relate to the physical transmission conditions and can be de-
rived from physical transmission parameters like a channel
coherence bandwidth or a coherence time. The data-related
transmission constraints relate to system specific con-
35   straints regarding for example the employed multiplexing
scheme for the data words, the structure of the data signal,

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the structure of the data blocks, the structure of the data
words or the structure of the data symbols.

The data symbols may be derived from the data signal in vari-
ous ways dependent on the transmit diversity scheme which is
used. If, for example, the transmit diversity scheme of per-
mutation is used, the data symbols contained in the data
words are permutations of information symbols comprised
within the data signal. As a further example, if the transmit
diversity scheme of block coding is used, the data symbols
contained in the data words are obtained from the information
symbols comprised within the data signal by means of permuta-
tion and basic arithmetic operations, such as negation and
complex conjugation.

The data signal from which the one or more data blocks are
generated can have any format. According to a preferred em-
bodiment, the data signal has the format of a sequence of
discrete information symbols. For example, the data signal
may have the structure of vectors, each vector comprising a
predefined number of information symbols. The nature of the
information symbols may depend on the specific wireless com-
munication system in which the multiplexing method according
to the invention is used. Many wireless communication systems
employ different types of information symbols for different
purposes. For example, some wireless communication systems
use data signals which comprise a preamble, one or more user
data sections or both a preamble and one or more user data
sections. Usually, the preamble has a predefined structure
and is utilized for purposes like channel estimation, fre-
quency synchronization and timing synchronization.

In the following, several exemplary data-related transmission
constraints are described in more detail. According to a
first embodiment, the data-related transmission constraint is
a predefined number N of data symbols to be comprised within
each data word which is to be multiplexed in the time domain.

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Usually, the number N of data symbols to be comprised within
each data word cannot arbitrarily be chosen because it may
depend for example on a code rate, on the condition that the
data blocks have to be orthogonal matrices or on the avail-
ability of memory resources within the multicarrier transmit
diversity system.

When the data words of a specific data block are to be multi-
plexed in the time domain, the number N of data symbols to be
comprised within each data word may represent the number of
time slots required for the transmission of a single data
word over a single subcarrier. On the other hand, when the
data words of a specific data block are to be multiplexed in
the frequency domain, the number N of data symbols to be com-
prised within each data word stands for the number of subcar-
riers required to transmit a single data word during a single
time slot.

Preferably, all data words of an individual data block com-
prise the same number of data symbols. If the data signal has
such a structure that the number of data symbols comprised
within each data word of a specific data block equals the
predefined number N of data symbols, the data words of this
data block may be multiplexed in the time domain. Otherwise,
i.e. if the data signal has such a structure that the number
of data symbols comprised within each data word of a specific
data block does not equal the predefined number N of data
symbols, the data words of this data block may be multiplexed
in the frequency domain. Such a distinction will become nec-
essary if the data signal or a portion thereof has a prede-
fined length because the predefined length may imply that the
total number N_b of data symbols which corresponds to the pre-
defined length of the data signal or a portion thereof is not
an integer multiple of the predefined number N of data sym-
bols which should be comprised within a data word to be mul-
tiplexed in the time domain. In such a situation integer mul-
tiples of the predefined number N of data symbols are ar-

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ranged in data blocks of data words which are multiplexed in
a time domain and a remainder $N_a = \mod(N_c/N)$ of data symbols
is arranged in a data block with data words which are multi-
plexed in the frequency domain.

Thus, by combining multiplexing in the time domain and in the
frequency domain, data symbol fitting problems resulting from
the predefined number N of data symbols to be comprised
within each data word which is to be multiplexed in the time
domain can be solved. Such data symbol fitting problems may
for example become relevant when the data signal or a portion
of the data signal has a predefined length because the wire-
less transmission system necessitates that the preamble por-
tion or the user data portion of a data signal comprises a
certain number of information symbols. Thus the data words of
all data blocks except for the last data block are multi-
plexed in the time domain and the data words of the last data
block are either multiplexed in the time domain or in the
frequency domain depending on whether or not the data words
of the last data block contain a number of data symbols which
equals the predefined number N of data symbols.

So far the data-related transmission constraint of a prede-
fined number N of data symbols to be comprised within each
data word has been illustrated. According to a second embodi-
ment, the data signal may comprise one or more periodic
structures and the data related transmission constraint may
be a preservation of the periodic structures such that the
periodic structures are still periodic on a receiver side.
The one or more periodic structures may be comprised within a
preamble of the data signal, for example in the form of two
or more identical preamble information symbols. Periodic
structures are advantageous because they allow the use of
synchronization algorithms with comparatively low complexity.

In case of multiplexing data symbols relating to periodic
structures in the time domain the periodicity of the periodic

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structures may get lost. Therefore, at least the data words
of data blocks which relate to the periodic structures or
parts of periodic structures are multiplexed in the frequency
domain. By multiplexing the data words of these data blocks
5   in the frequency domain it can be ensured that the periodic-
ity of the periodic structures is maintained.

When the data words of data blocks generated from periodic
structures or portions thereof are multiplexed in the fre-
10 quency domain, the data words of data blocks generated from
the remaining data signal are preferably multiplexed in the
time domain. If, for example, the data words of data blocks
generated from a preamble comprising periodic structures are
multiplexed in the frequency domain, the data words of data
15 blocks generated from a corresponding user data section may
be multiplexed at least partly in the time domain.

Instead of data-related transmission constraints or in addi-
tion to data-related transmission constraints physical trans-
20 mission constraints can be taken into account when deciding
if the data words of one or more specific data blocks are to
be multiplexed in the time domain or in the frequency domain.
According to a preferred embodiment, the decision is made
based on simultaneously evaluating a combination of one or
25 more data-related transmission constraints and one or more
physical transmission constraints.

The physical transmission constraints may be determined based
on at least one of a channel coherence bandwidth
30

$$B_c \approx 1 / \tau_{rms}$$

(1)

and a coherence time
35

$$t_c \approx 1 / (2 \cdot f_D)$$ (2)

wherein f_0 is the doppler frequency and τ_{rms} is the root mean square of the delay spread of the channel impulse response.

Many transmit diversity schemes require constant or at least approximately constant channel parameters during transmission of one data word. If the data words are to be multiplexed in the frequency domain, a comparatively large coherence band width is required. This means that the relation

$$B_c \gg N/T \qquad (3)$$

has to be fulfilled at least approximately, wherein N is the number of data symbols per data word and T is the duration of one of the data symbols, i.e. the duration of one time slot. A comparatively large coherence bandwidth requires that the channel parameters of N adjacent subcarriers have to be almost constant.

On the other hand, if the data words are to be multiplexed in the time domain, a comparatively large coherence time is required. This means that the relation

$$t_c \gg T \cdot N \qquad (4)$$

has to be fulfilled at least approximately. In other words: N subsequent data symbols have to have nearly constant channel parameters, i.e. the channel parameters for a single subcarrier have to remain constant for a period of $N \cdot T$.

The physical transmission constraint may be determined by assessing if one or both of the relations (3) and (4) are fulfilled. Dependent on which of the two relations (3) and (4) is fulfilled best it is decided that the data words of the data blocks are to be multiplexed either in the time domain or in the frequency domain as a general rule. Deviations from this general rule may become necessary due to data-related

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transmission constraints. For example, the data symbol fit-
ting problem or the problem encountered with periodic struc-
tures may necessitate that although multiplexing in the time
domain is generally to be preferred, the data words of at
least some data blocks have to be multiplexed in the fre-
quency domain. As a further example, changing transmission
conditions may necessitate that the data words of some data
blocks have to be multiplexed in the time domain and the data
words of other data blocks have to be multiplexed in the fre-
quency domain. As a third example, the data words of data
blocks generated from a preamble may be multiplexed in the
time domain and the data words of data blocks generated from
a user data section may be multiplexed in the frequency do-
main. Such a combination has the advantage that the above-
mentioned data symbol fitting problem, which usually is most
relevant for the user data section, can be avoided while the
multiplexing in the time domain of the data words of data
blocks generated from the preamble allows a good channel es-
timation.

It was mentioned above that in order to achieve full diver-
sity each information symbol has to be transmitted from each
transmitter antenna. A further requirement of full transmit
diversity is that the antenna signals are orthogonal to each
other. This means that the data symbols have to be modulated
onto subcarriers which are orthogonal to each other. However,
the invention can also be practiced in case the subcarriers
are not orthogonal.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages of the invention will become apparent by
reference to the following description of a preferred embodi-
ment of the invention in the light of the accompanying draw-
ings, in which :

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Fig. 1   shows a data signal in the form of a physical burst
          to be processed in accordance with the invention;

Fig. 2   is a block diagram of a transceiver for wireless
          communication adapted to multiplex data words in
          accordance with the invention;

Fig. 3   shows several modulation schemes defined in the
          HIPERLAN/2 standard;

Fig. 4   shows the block code encoder of the transceiver de-
          picted in Fig. 2;

Fig. 5   shows the configuration of a transmit antenna di-
          versity scheme;

Fig. 6   is a schematic diagram of multiplexing data words
          in the time domain in accordance with the inven-
          tion; and

Fig. 7   is a schematic diagram of multiplexing data words
          in the frequency domain in accordance with the in-
          vention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Although the present invention can be used in any multicar-
rier transmit diversity system which employs a transmit di-
versity scheme allowing to generate data blocks having a
structure as described above, the following description of
preferred embodiments is examplarily set forth with respect
to a multicarrier system which employs orthogonal frequency
division multiplexing (OFDM) and which utilizes block coding
for generating data blocks from a data signal.

The exemplary multicarrier system described below is derived
from the European wireless local area network (WLAN) standard

high performance radio local area network type 2
(HIPERLAN/2). HIPERLAN/2 systems are intended to be operated
in the 5 GHz frequency band. A system overview of HIPERLAN/2
is given in ETSI TR 101 683, Broadband Radio Access Networks
5   (BRAN); HIPERLAN Type 2; System Overview, V1.1.1 (2000-02)
and the physical layer of HIPERLAN/2 is described in ETSI TS
101 475; Broadband Radio Access networks (BRAN); HIPERLAN
Type 2; Physical (PHY) Layer, V1.1.1 (2000-04). The multicar-
rier scheme of OFDM, which is specified in the HIPERLAN/2
10   standard, is very robust in frequency selective environments.

Up to now, the HIPERLAN/2 system and many other wireless com-
munications systems do not support transmit diversity in
spite of the fact that transmit diversity would improve the
15   transmission performance and reduce negative effects of fast
fading like Rayleigh fading. However, applying standard
transmit diversity schemes to multicarrier communications
systems may lead to various problems which are hereinafter
examplarily described with respect to the HIPERLAN/2 system.
20

In Fig. 1 a typical physical burst of HIPERLAN/2 is illus-
trated. The physical burst comprises a preamble consisting of
preamble symbols and a user data section consisting of user
data symbols. In HIPERLAN/2 five different physical bursts
25   are specified and each kind of physical burst has a unique
preamble. However, the last three preamble symbols constitute
a periodic structure which is identical for all preamble
types. This periodic structure consists of a short OFDM sym-
bol C32 of 32 samples followed by two identical regular OFDM
30   symbols C64 of 64 samples. The short OFDM symbol C32 is a cy-
clic prefix which is a repetition of the second half of one
of the C64 OFDM symbols. The so-called C-preamble depicted in
Fig. 1 is used in HIPERLAN/2 for channel estimation, fre-
quency synchronization and timing synchronization. The peri-
35   odic structure within the C-preamble is necessary in order to
allow the use of synchronization algorithms with compara-
tively low complexity.

The user data section of the physical burst depicted in Fig.
1 comprises a variable number N_{sym} of OFDM symbols required to
transmit a specific protocol data unit (PDU) train. Each OFDM
symbol of the user data section consists of a cyclic prefix
and a useful data part. The cyclic prefix consists of a cy-
clic continuation of the useful data part and is inserted be-
fore it. Thus, the cyclic prefix is a copy of the last sam-
ples of the useful data part. The length of the useful data
part is equal to 64 samples and has a duration of 3,2 µs. The
cyclic prefix has a length of either 16 (mandatory) or 8 (op-
tional) samples and a duration of 0,8 µs or 0,4 µs, respec-
tively. Altogether, a OFDM symbols thus has a length of ei-
ther 80 or 72 samples corresponding to a symbol duration of
4,0 µs or 3,6 µs, respectively. An OFDM symbol therefore has
an extension in the time domain. A OFDM symbol further has an
extension in the frequency domain. According to HIPERLAN/2, a
OFDM symbol extends over 52 subcarriers. 48 subcarriers are
reserved for complex valued subcarrier modulation symbols and
4 subcarriers are reserved for pilots.

From the above it becomes clear that the HIPERLAN/2 physical
burst depicted in Fig. 1 has a predefined length both in a
time direction and in a frequency direction. Moreover, the
physical burst of Fig. 1 comprises a periodic structure. It
are among others these features of the physical burst of Fig.
1 which may lead to problems when the HIPERLAN/2 system or a
similar wireless communication system has to be adapted to
transmit diversity.

For typical HIPERLAN/2 scenarios the above relation (4) is
usually fulfilled because the doppler frequency f_D is com-
paratively low. However, especially in outdoor environments,
relatively large delay spreads can occur. Consequently, rela-
tion (3) cannot always be fulfilled. Therefore, a transmit
diversity scheme like STBC multiplexing in the time domain
should generally be a preferred transmit diversity scheme for

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a HIPERLAN/2 scenario from the point of view that the channel
over one space-time data word should be as constant as possi-
ble. However, severe problems arise when STBC is applied to
physical bursts having the structure depicted in Fig. 1 or a
5   similar structure.

Both the physical burst and the OFDM symbols comprised
therein have predefined dimensions in the time domain and in
the frequency domain. Concurrently, STBC requires that each
10   STBC data word has a predetermined length N. Thus, data unit
fitting problems arise if the dimension of e.g. an OFDM sym-
bol of the preamble or of the user data section cannot be
mapped on an integer multiple of the length of one STBC data
word. Moreover, when applying STBC to the periodic C-preamble
15   depicted in Fig. 1, the periodicity of the C-preamble gets
lost. This is due to the fact that the one or more STBC data
words relating to the second C64 OFDM symbol will no longer
be equal to the one or more STBC data words relating to the
first C64 OFDM symbol. The loss of periodicity, however,
20   leads to the problem that the symbol synchronization algo-
rithms which make use of a periodic structure within the pre-
amble can no longer be employed. Also, the C32 OFDM symbol
cannot serve any longer as a guard interval separating the
OFDM symbols within the preamble. The reason therefore is
25   that in case of multipath propagation the first C64 OFDM sym-
bol interferes with the second C64 OFDM symbol which is no
longer equal to the first C64 OFDM symbol.

The above problems and further problems not explicitly dis-
30   cussed above do not occur when the data words are multiplexed
in accordance with the invention. In Fig. 2, the physical
layer of a transceiver 10 which is adapted to implement the
method according to the invention is illustrated. The trans-
ceiver 10 comprises a scrambler 12, an FEC coding unit 14, an
35   interleaving unit 16, a mapping unit 18, an OFDM unit 20, a
burst forming unit 22, a block code encoder 24, a multiplexer
26, a radio transmitter 30 and a control unit 32. The block

code encoder 24 and the multiplexer 26 together form an encoder/multiplexer unit 28.

The transceiver 10 depicted in Fig. 1 receives as input signal a PDU train from a data link control (DLC). Each PDU train consists of information bits which are to be framed into a physical burst, i.e. a sequence of OFDM symbols to be encoded, multiplexed and transmitted.

Upon receipt of a PDU train the transmission bit rate within the transceiver 10 is configured by choosing an appropriate physical mode based on a link adaption mechanism. A physical mode is characterized by a specific modulation scheme and a specific code rate. In the HIPERLAN/2 standard several different coherent modulation schemes like BPSK, QPSK, 16-QAM and optional 64-QAM are specified. Also, for forward error control, convolutional codes with code rates of 1/2, 9/16 and 3/4 are specified which are obtained by puncturing of a convolutional mother code of rate 1/2. The possible resulting physical modes are depicted in Fig. 3. The data rate ranging from 6 to 54 Mbit/s can be varied by using various signal alphabets for modulating the OFDM subcarriers and by applying different puncturing patterns to a mother convolutional code.

Once an appropriate physical mode has been chosen, the N_{PDU} information bits contained within the PDU train are scrambled with the length-127 scrambler 12. The scrambled bits are then output to the FEC coding unit 14 which encodes the N_{PDU} scrambled PDU bits according to the previously set forward error correction.

The encoded bits output by the FEC coding unit 14 are input into the interleaving unit 16 which interleaves the encoded bits by using the appropriate interleaving scheme for the selected physical mode. The interleaved bits are input into the mapping unit 18 where sub-carrier modulation by mapping the interleaved bits into modulation constellation points in ac-

cordance with the chosen physical mode is performed. As men-
tioned above, the OFDM subcarriers are modulated by using
BPSK, QPSK, 16-QAM or 64-QAM modulation depending on the
physical mode selected for data transmission.

The mapping unit 18 outputs a stream of complex valued sub-
carrier modulation symbols which are divided in the OFDM unit
in groups of 48 complex numbers. In the OFDM unit a complex
base band signal is produced by OFDM modulation as described
in ETSI TS 101 475, Broadband Radio Access Networks (BRAN);
HIPERLAN Type 2; Physical (PHY) Layer, V1.1.1 (2000-04).

The complex base band OFDM symbols generated within the OFDM
unit 20, where pilot subcarriers are inserted, are input into
the physical burst unit 22, where an appropriate preamble is
appended to the PDU train and the physical burst is built.
The physical burst produced by the physical burst unit 22 has
a format as depicted in Fig. 1. The physical burst unit 22
thus outputs a sequence of complex base band OFDM symbols in
the form of the physical burst to the block code encoder 24.

The function of the block code encoder 24 is now generally
described with reference to Fig. 4. In general, the block
code encoder 24 receives an input signal in the form of a se-
quence of vectors $X = [X_1 X_2 \dots X_K]^T$ of the length K. The block
code encoder 24 encodes each vector X and outputs for each
vector X a data block comprising a plurality of signal vec-
tors $C^{(1)}, C^{(2)}, \dots, C^{(M)}$ as depicted in Fig. 4. Each signal vec-
tor $C^{(1)}, C^{(2)}, \dots, C^{(M)}$ corresponds to a single data word. Thus,
the data block generated from the vector X comprises M data
words wherein M is the number of transmitter antennas.

Each data word $C^{(i)}$ with $i = 1 \dots M$ comprises N data symbols,
i.e. each data word $C^{(i)}$ has a length of N. The value of N
cannot be freely chosen since the matrix C spanned by the
data words $C^{(i)}$ has to be orthogonal in this embodiment. Sev-
eral examples for data blocks in the form of orthogonal code

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matrices C are described in US 6,088,408. In the block coding
approach described in the present embodiment all data symbols
c_j^k of the code matrix C are derived from the components of
the input vector X and are simple linear functions thereof or
of its complex conjugate.

If a receive signal vector Y at one receive antenna is de-
noted by $Y = [Y_1 Y_2 \ldots Y_N]^T$, the relationship between Y and the
code matrix C is as follows:

$$\begin{vmatrix} Y_2 \\ \ldots \\ Y_N \end{vmatrix} = \begin{vmatrix} c_2 & \cdots & & c_2 \\ \ldots & & \ddots & \ldots \\ c_N^{(1)} & c_N^{(2)} & \cdots & c_N^{(M)} \end{vmatrix} \cdot \begin{vmatrix} h \\ \ldots \\ h^{(M)} \end{vmatrix} \qquad (5)$$

where $h^{(i)}$ represents the channel coefficient of the channel
from the i-th transmit antenna to the receive antenna. A gen-
eralization to more receive antennas is straightforward.

In the following examples of possible block code matrices for
two and three transmitter antennas, respectively, are dis-
cussed in more detail. The configuration of a wireless commu-
nication system with two transmit antennas and one receive
antenna is depicted in Fig. 5. For two transmit antennas one
possible block code matrix C with a code rate R = 1 is :

$$C = \begin{bmatrix} X_1 & X_2 \\ -X_2^* & X_2^* \end{bmatrix}$$

(6)

For three transmit antennas one possible block code matrix C
with a code rate R = 0,5 is:

$$
C = \begin{bmatrix}
- X_4 & - X_3 & X_2 \\
X_1^* & X_2^* & X_3^* \\
- X_2^* & X_1^* & - X_4^* \\
- X_3^* & X_4^* & X_1^* \\
- X_4^* & - X_3^* & X_2^*
\end{bmatrix}
\tag{7}
$$

The code rate R is defined as the ratio of the length K of
the input vector X and the length N of each code word $C^{(i)}$:

$$
R = K/N
\tag{8}
$$

As can be seen from Fig. 4, the block code encoder 24 outputs
for each data signal in the form of a vector X a data block
in the form of a matrix C. The data block output by the block
code encoder 24 is input into the multiplexer 26 which multi-
plexes the data words (vectors $C^{(i)}$) of each data block in ac-
cordance with an externally provided control signal either in
the time domain or in the frequency domain. The control sig-
nal is generated by the control unit 32 based on an assess-
ment of the transmission constraints. The assessment of the
transmission constraints and the controlling of the multi-
plexer 26 by means of the control unit 32 will be described
later in more detail.

In the multicarrier scheme OFDM, the output of the block code
encoder 24 is modulated onto subcarriers which are orthogonal
to each other. There exist essentially two possibilities to

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multiplex a data block comprising individual data words in an
OFDM system. According to a first possibility depicted in
Fig. 6, the data words of a specific data block are extended
in the time direction (STBC). In other words: The data words
are multiplexed in the time domain. According to a second
possibility, the data words of a data block are extended in
the frequency direction as depicted in Fig. 7. This means
that the data words are multiplexed in the frequency domain.
Multiplexing the data words of a data block in the form of a
code matrix in the frequency domain will in the following be
referred to as space-frequency block coding (SFBC).

As can be seen from Figs. 6 and 7, the individual data words
of a data block are transmitted from different transmit an-
tennas. According to the multiplexing scheme of Fig. 6, an
individual data block is transmitted on an individual subcar-
rier over a time interval of $N \cdot T$, wherein N is the number
of data symbols per data word and T is the duration of one of
the data symbols. According to the multiplexing scheme of
Fig. 7, an individual data block is spread over N subcarriers
and is transmitted during a time interval of T. It can
clearly be seen that the multiplexing scheme of Fig. 6 can
generally be employed when the relation (4) is fulfilled and
the multiplexing scheme of Fig. 7 can generally be employed
when the relation (3) is satisfied.

The encoded and multiplexed output signal of the en-
coder/multiplexer unit 28 is input into the radio transmitter
30. The radio transmitter 30 performs radio transmission over
a plurality of transmit antennas by modulating a radio fre-
quency carrier with the output signal of the en-
coder/multiplexer unit 28. The transceiver 10 of Fig. 2 fur-
ther comprises a receiver stage not depicted in Fig. 2. The
receiver stage has a physical layer with components for per-
forming the inverse operations of the components depicted in
Fig. 2. For example, the receiver stage comprises a descram-

bler, a FEC decoding unit, a demultiplexer/decoder unit with
a demultiplexer and a block code decoder, etc.

Now, the control of the multiplexer 26 will be described in
more detail with reference to both physical and data-related
transmission constraints that may occur if physical bursts as
the one depicted in Fig. 1 are employed. In accordance with
typical HIPERLAN/2 scenarios, it is supposed that relation
(4) is fulfilled and that it cannot always be guaranteed that
relation (3) is fulfilled. This corresponds to the realistic
situation that the basic performance of STBC transmission is
better than the basic performance of SFBC transmission. Basic
performance here means that only physical transmission con-
straints are taken into account. In such a case the control
unit 32 may decide that the data blocks have to be multi-
plexed in the time domain. However, if the physical transmis-
sion parameters change, there might occur the case where re-
lation (4) is no longer fulfilled whereas relation (3) is
fulfilled at least approximately. In this case the control
unit 32 will decide that the data words of the data blocks
are no longer multiplexed in the time domain. Instead, the
control unit 32 controls the multiplexer 26 such that the
data words of the data blocks are multiplexed in the fre-
quency domain.

So far only physical transmission constraints have been con-
sidered. Should data-related transmission constraints also be
of importance, the control unit 32 controls the multiplexer
26 by additionally taking into account data-related transmis-
sion constraints.

It has been mentioned above that the transmission constraints
which have to be considered in context with the physical
burst depicted in Fig. 1 are the preservation of a periodic
structure in the C-preamble and the provision of a predefined
number N of data symbols in each data word which is to be

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multiplexed in the time domain. These two data-related trans-
mission constraints can occur in several combinations.

According to a first scenario, the data signal has the struc-
ture of the physical burst depicted in Fig. 1 and comprises a
user data section and a preamble with a periodic structure.
It is further supposed that the data-related transmission
constraint of preserving the periodic structure has to be
taken into account while no data symbol fitting problem oc-
curs with respect to the user data section. In such a case
the data words of data blocks relating to the preamble are
multiplexed in accordance with SFBC in the frequency domain
and the data words of data blocks relating to the user data
section are multiplexed in accordance with STBC in the time
domain. By multiplexing the data words derived from the pre-
amble in the frequency domain a preservation of the order of
the C32 OFDM symbols and the two C64 OFDM symbols can be
achieved.

According to a second scenario derived from the physical
burst depicted in Fig. 1, the periodic structure within the
preamble has to be preserved and additionally the data symbol
fitting problem has to be taken into account with respect to
the user data section. Like in the first scenario, the data
words of data blocks derived from the preamble are multi-
plexed in accordance with SFBC in the frequency domain. Due
to the data symbol fitting problem the data words of the last
data block relating to the user data structure contains less
than the predefined number N of data symbols contained in
data words of the previous data blocks. Therefore, only the
data words (containing the predefined number N of data sym-
bols) of the previous data blocks are multiplexed in accor-
dance with STBC in the time domain. The data words of the
last data block contain $N_k = mod(N_p/N)$ data symbols and are
multiplexed in accordance with SFBC in the frequency domain,
wherein N_p is the total number of data symbols to be trans-
mitted over one transmit antenna.

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According to a third scenario, the data-related transmission constraint of the preservation of a periodic structure within the preamble is not relevant but the data symbol fitting problem is relevant with respect to the user data section. In this case the data words of data blocks relating to the preamble are multiplexed in accordance with STBC in the time domain and the data words of data blocks relating to the user data section are multiplexed as described above for the second scenario. In other words: The data words of the last data block have a length of N_E data symbols and the data words of the previous data blocks have the predefined length of N data symbols.

According to a fourth scenario, the data-related transmission constraint of preserving a periodic structure has not to be taken into account and the physical transmission constraint of $E_c \gg N/T$ is at least approximately fulfilled. In this case the data words of data blocks relating to the preamble are multiplexed in accordance with STBC in the time domain and the data words of data blocks relating to the user data section are multiplexed in accordance with SFBC in the frequency domain. By using STBC for the preamble a good channel estimation can be performed. Due to the use of STBC for the preamble the slightly worse performance of SFBC can be compensated by means of receiver algorithms for interference suppression based on the good channel estimation. Using STBC for the preamble and SFBC for the user data section has the advantage that data symbol fitting problems with respect to the user data section do not appear.

Additional scenarios based on further combinations of data-related and physical transmission constraints can easily be realized in accordance with the invention. Also, the invention can easily be applied to data signals having a structure different from the structure of the physical burst depicted in Fig. 1. Although the invention is preferably practiced

with the transmit diversity scheme of a combination of STBC
and SFBC, other transmit diversity schemes can be used as
well.

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CLAIMS

1. A method of multiplexing data words in a multicarrier
    transmit diversity system, comprising:

    a) generating a plurality of data blocks (C), each
        data block (C) comprising data words ($C^{(i)}$) and each
        data word ($C^{(i)}$) containing data symbols ($c_i^{(i)}$) de-
        rived from a data signal;

    b) determining for one or more data blocks (C) in de-
        pendence on at least one transmission constraint if
        the data words ($C^{(i)}$) of said one or more data
        blocks (C) are to be multiplexed in the time domain
        or in the frequency domain; and

    c) multiplexing the data words ($C^{(i)}$) of the data
        blocks (C) in accordance with the determination in
        step b).

2. The method according to claim 1,
    wherein the data signal comprises at least one of a pre-
    amble and a user data section.

3. The method according to claim 1 or 2,
    wherein the at least one transmission constraint com-
    prises a data-related transmission constraint.

4. The method according to claim 3,
    wherein the data-related transmission constraint is a
    pre-defined number (N) of data symbols ($c_i^{(i)}$) to be com-
    prised within each data word ($C^{(i)}$) which is to be multi-
    plexed in the time domain.

5. The method according to claim 4,
    wherein the data words ($C^{(i)}$) containing the predefined
    number (N) of data symbols ($c_i^{(i)}$) are multiplexed in the
    time domain and the data words ($C^{(i)}$) containing more or

less data symbols ($c_j^{(i)}$) are multiplexed in the frequency domain.

6. The method according to claim 4 or 5,
    wherein the data signal or a portion thereof has a predefined length and wherein integer multiples of the predefined number of data symbols ($c_j^{(i)}$) are arranged in data blocks (C) with data words ($C^{(i)}$) which are multiplexed in the time domain and a remainder of data symbols ($c_j^{(i)}$) is arranged in data blocks (C) with data words ($C^{(i)}$) which are multiplexed in the frequency domain.

7. The method according to claim 6,
    wherein the user data section of the data signal has the predefined length.

8. The method according to claim 7,
    wherein the data words ($C^{(i)}$) of data blocks (C) relating to the preamble are either multiplexed completely in the frequency domain or completely in the time domain dependent on the transmission constraint.

9. The method according to one of claims 1 to 8,
    wherein the data signal comprises one or more periodic structures (C32, C64).

10. The method according to claim 9,
    wherein the one or more periodic structures (C32, C64) are contained within the preamble.

11. The method according to claim 9 or 10,
    wherein the data-related transmission constraint is a preservation of the one or more periodic structures (C32, C64).

12. The method according to one of claims 9 to 11,

wherein at least the data words $(C^{(i)})$ of data blocks (C)
relating to the periodic structures (C32, C64) are mul-
tiplexed in the frequency domain.

13. The method according to claim 12,
    wherein the data words $(C^{(i)})$ of data blocks (C) relating
    to the user data section are multiplexed in the time do-
    main.

14. The method according to one of claims 1 to 13,
    wherein the at least one transmission constraint com-
    prises a physical transmission constraint.

15. The method according to claim 14,
    wherein the physical transmission constraint is deter-
    mined based on at least one of a coherence bandwidth and
    a coherence time.

16. The method according to claim 15,
    wherein the physical transmission constraint is deter-
    mined by assessing if the relationship $B_c \gg N/T$ is ful-
    filled, wherein B_c is the coherence bandwidth, N is the
    number of data symbols $(c_i^{(i)})$ per data word $(C^{(i)})$ and T
    is the duration of one of the data symbols $(c_j^{(i)})$.

17. The method according to claim 15 or 16,
    wherein the physical transmission constraint is deter-
    mined by assessing if the relationship $t_c \gg N \cdot T$ is ful-
    filled, wherein t_c is the coherence time, N is the num-
    ber of data symbols $(c_j^{(i)})$ per data word $(C^{(i)})$ and T is
    the duration of one of the data symbols $(c_j^{(i)})$.

18. The method according to claim 16 or 17,
    wherein, when the physical transmission constraint
    $B_c \gg N/T$ is at least approximately fulfilled, the data
    words $(C^{(i)})$ of data blocks (C) relating to the preamble
    are multiplexed in the time domain and the data words

$\{C^{(i)}\}$ of data blocks (C) relating to the user data sequence are multiplexed in the frequency domain.

19. The method according to one of claims 1 to 18, wherein the data blocks (C) are obtained from the data signal by means of block coding or by means of permutation.

20. The method according to one of claims 1 to 19, wherein the data symbols $\{c_j^{(i)}\}$ are modulated onto subcarriers which are orthogonal to each other.

21. A multiplexer (26) adapted to multiplex data words in accordance with the method according to one of claims 1 to 20.

22. A demultiplexer adapted to demultiplex data words multiplexed by the multiplexer of claim 21.

23. A transceiver for wireless communication, comprising at least one of a multiplexer according to claim 21 and a demultiplexer according to claim 22.
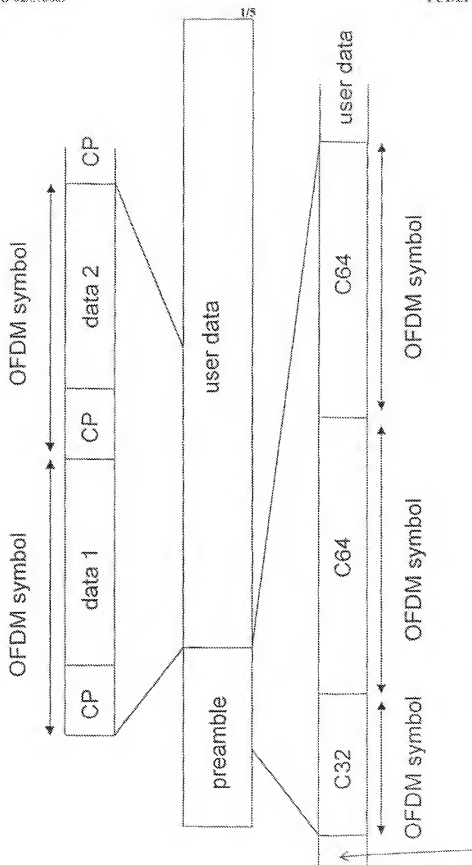
60

Fig. 1

PDU train from DLC (transmit)

scrambling — 12

FEC coding — 14

interleaving — 16

mapping — 18

OFDM — 20

PHY bursts — 22

Block Code Encoder — 24

Multi-plexer — 28

Control Unit — 32

radio transmitter — 30

26

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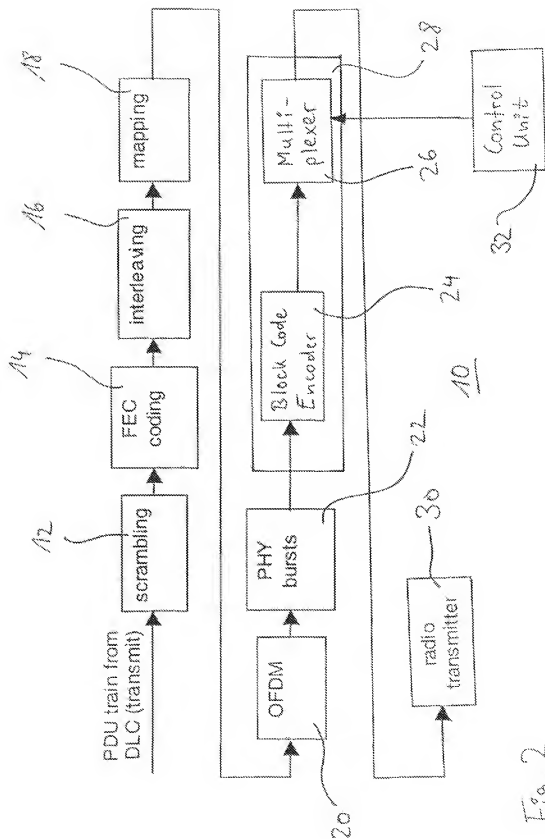
Fig. 2

modulation scheme	code rate	bit rate
BPSK	1/2	6 Mbps
BPSK	3/4	9 Mbps
QPSK	1/2	12 Mbps
QPSK	3/4	18 Mbps
16-QAM	9/16	27 Mbps
16-QAM	3/4	36 Mbps
64-QAM	3/4	54 Mbps

Fig. 3
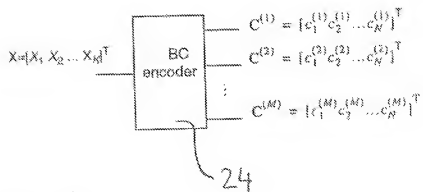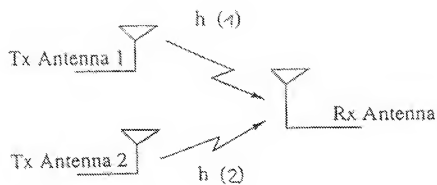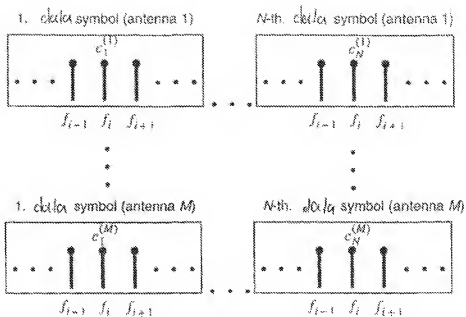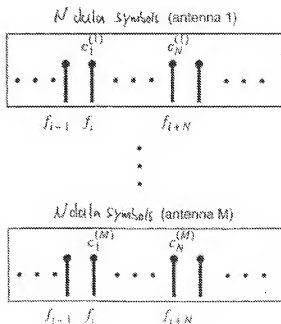
$X = [X_1 \ X_2 \ ... \ X_M]^T$ → BC encoder →

$C^{(1)} = [c_1^{(1)} c_2^{(1)} ... c_N^{(1)}]^T$

$C^{(2)} = [c_1^{(2)} c_2^{(2)} ... c_N^{(2)}]^T$

$\vdots$

$C^{(M)} = [c_1^{(M)} c_2^{(M)} ... c_N^{(M)}]^T$

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Fig. 4

Fig. 5

1. data symbol (antenna 1)   N-th. data symbol (antenna 1)
$c_1^{(1)}$ $c_N^{(1)}$
f_{i-1} f_i f_{i+1} f_{i-1} f_i f_{i+1}

1. data symbol (antenna M)   N-th. data symbol (antenna M)
$c_1^{(M)}$ $c_N^{(M)}$
f_{i-1} f_i f_{i+1} f_{i-1} f_i f_{i+1}

Fig. 6

N data symbols (antenna 1)
$c_1^{(1)}$ $c_N^{(1)}$
f_{i-1} f_i f_{i+N}

N data symbols (antenna M)
$c_1^{(M)}$ $c_N^{(M)}$
f_{i-1} f_i f_{i+N}

Fig. 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7   H04L5/02   H04L1/00   H04B7/06   H04B7/12   H04L1/06
         H04L1/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   H04L   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
X	MUDULODU S ET AL: "A transmit diversity scheme for frequency selective fading channels" GLOBECOM '00 – IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE. CONFERENCE RECORD (CAT. NO.00CH37137), PROCEEDINGS OF GLOBAL TELECOMMUNICATIONS CONFERENCE, SAN FRANCISCO, CA, USA, 27 NOV.-1 DEC. 2000, pages 1089-1093 vol.2, XP002172508 2000, IEEE, Piscataway, NJ, USA ISBN: 0-7803-6451-1 cited in the application the whole document	1-23

—/—

[X] Further documents are listed in the continuation of box C.   [ ] Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 July 2002	17/07/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Toumpoulidis, T

Form PCT/ISA/210 (second sheet) (July 1992)

C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LEE K F ET AL: "A space-frequency transmitter diversity technique for OFDM systems" GLOBECOM '00 – IEEE. GLOBAL TELECOMMUNICATIONS CONFERENCE. CONFERENCE RECORD (CAT. NO.00CH37137), PROCEEDINGS OF GLOBAL TELECOMMUNICATIONS CONFERENCE, SAN FRANCISCO, CA, USA, 27 NOV.-1 DEC. 2000, pages 1473-1477 vol.3, XP002172509 2000, Piscataway, NJ, USA, IEEE, USA ISBN: 0-7803-6451-1 the whole document	1-23
A	ALAMOUTI S M: "A simple transmit diversity technique for wireless communications" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,IEEE INC. NEW YORK,US, vol. 16, no. 8, October 1998 (1998-10), pages 1451-1458, XP002100058 ISSN: 0733-8716 the whole document	1-23